STATE OF ILLINOIS
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DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS—NO. 172

STRUCTURAL HISTORY OF THE CENTRALIA AREA

BY

ROBERT L. BROWNFIELD

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

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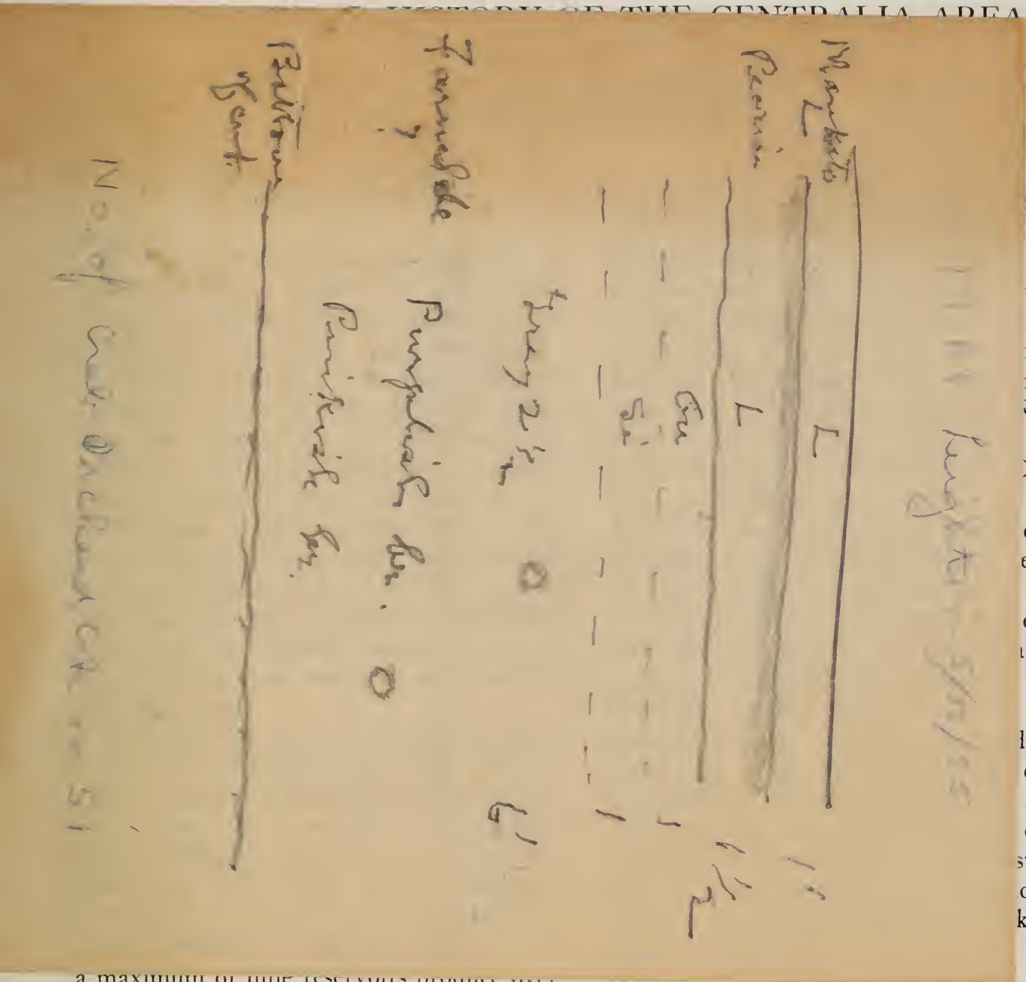
CONTENTS

ILLUSTRATIONS

TABLE



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TECTONIC ENVIRONMENT

The tectonic environment and stratigraphy of the Centralia area constitute the background against which the structural data presented in this report must be viewed. The Centralia area is about 50 miles from the west boundary of the Pennsylvanian outcrop area of the Eastern Interior basin (see fig. 1). The area is divided by the north-south axis of the DuQuoin monocline[1] into two almost equal

[1]This structure, originally named the DuQuoin monocline for the area about 30 miles south of the Centralia area, has been called the DuQuoin-Centralia monocline in several reports. As there is no longer any doubt about the continuity of the monocline as a single structure from DuQuoin into the Centralia area, the hyphenated term is here dropped.

STRUCTURAL HISTORY OF THE CENTRALIA AREA

BY

ROBERT L. BROWNFIELD

INTRODUCTION

The Centralia area, as designated in this report, consists of 256 square miles in Clinton, Jefferson, Marion, and Washington counties in south-central Illinois (figs. 1 and 2). The east and west boundaries of the area are each eight miles from the Third Principal Meridian; the north and south boundaries are 14 and 2 miles, respectively, from the base line.

The study is based on data from electric and radioactivity well logs, supplemented by sample studies and by driller's logs of cable-tool and rotary wells. Two structure maps and five isopach maps were constructed from these data and are presented with this report.

Both coal and oil are produced commercially in the Centralia area. The Herrin (No. 6) coal is worked in the Glen Ridge mine under Junction City. Four other mines formerly recovered coal from this same seam but are no longer operating. Oil is produced in 16 fields (fig. 2, table 1) in the Centralia area and from 15 pay zones; a maximum of nine reservoirs produce over a single structure, the Salem anticline. The rocks that yield oil range in age from Ordovician to Pennsylvanian.

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Special acknowledgment is due St. Louis University, under whose auspices a reconnaissance of the problem was conducted, and to the Department of Geology of the University of Illinois, to whom the report was submitted in partial fulfillment of the requirement for the degree of Master of Science. Jack Hough was faculty advisor, and it is the writer's pleasure to acknowledge his assistance.

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Fig. 1.—Location of the Centralia area in relation to regional features.

parts. The west half is on the shelf portion of the Eastern Interior basin and the east half is on the slope of that deeper part of the Eastern Interior basin which Bell (1941) called the *Illinois basin.* As the DuQuoin monocline is post-Mississippian in age, its effects on sedimentation are limited to the Pennsylvanian part of the stratigraphic section.

STRATIGRAPHY

The stratigraphy of the Centralia area is summarized in the columnar section (fig. 3). The upper part of the Pennsylvanian system, the McLeansboro and Carbondale groups, is characterized by silty shales with numerous thin coal and limestone markers and with a few thin, locally developed sandstones. The highest marker bed common throughout the area is the Shoal Creek limestone, which in the Centralia area is a light-colored, slightly sandy, hard limestone 8 to 10 feet thick. It is characterized on electric logs by spontaneous potential values that are unusually high for a Pennsylvanian limestone. The base of the Shoal Creek

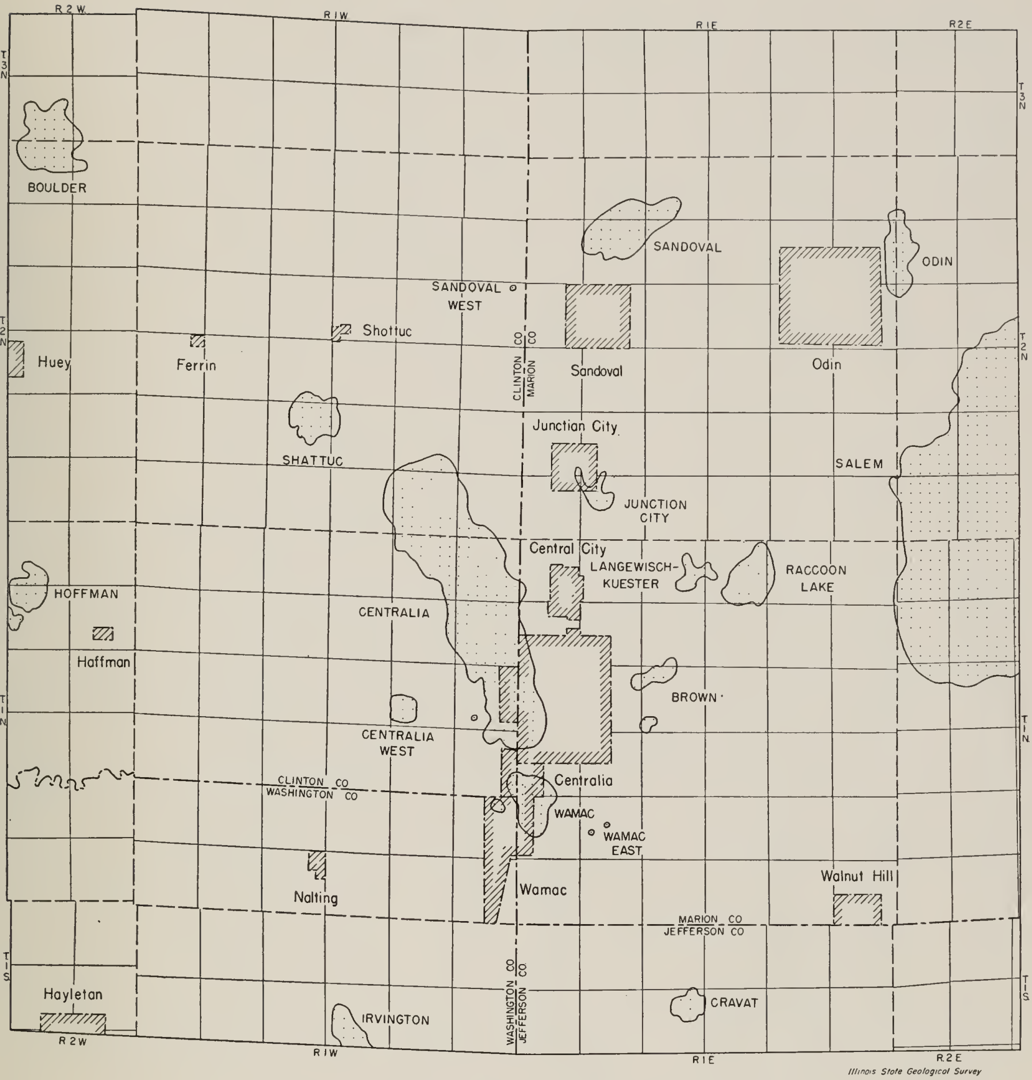

FIG. 2.—Towns and oil fields in the Centralia area.

limestone has been used as the structure horizon for figure 10 and as the upper marker horizon for the isopach in figure 9.

Coal No. 4 is the lowest Pennsylvanian marker which can be definitely identified with confidence throughout the area. For this reason it, and not the base of the Carbondale group, is used as the dividing line between the lower and upper Pennsylvanian strata in this area. Coal No. 4 is recognized by the thin limestone immediately above it (in electric logs the two beds produce a small but characteristic double resistivity peak) and by the monotonous shale section, 40-80 feet thick, which separates it from the limestone and coal complex between the No. 5 and No. 7 coals. Coal No. 4 is the upper datum horizon of figure 8, and the lower datum horizon of figure 9.

The lower Pennsylvanian—the Tradewater and Caseyville groups—consists of thick sandstones and sandy shales. Coal and limestone markers are few and erratic.

The Chester series (Butts, 1925; Folk and Swann, 1946; Swann and Atherton, 1948; Workman, 1940)—the upper part

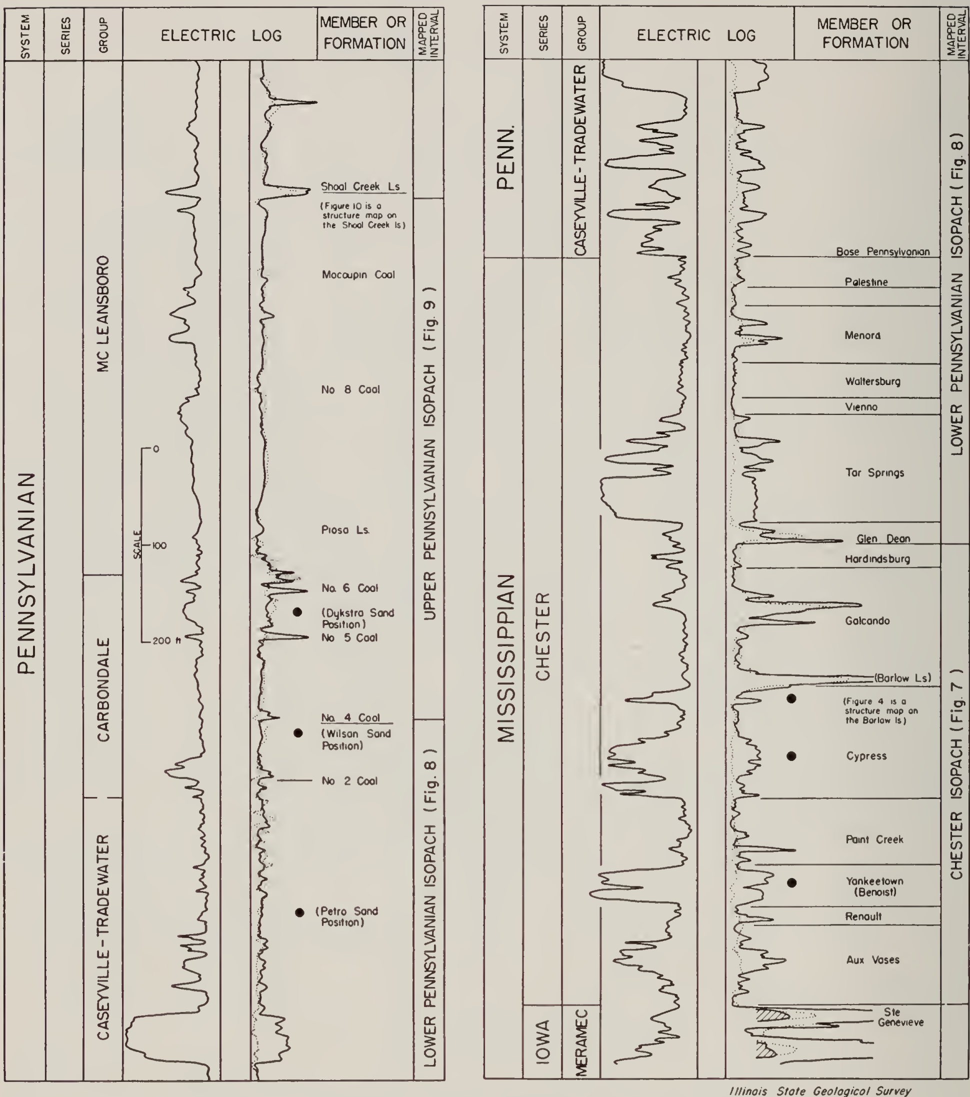

FIG. 3.—Geologic column, pay zones, and typical electric log in the Centralia area. The electric log used above the Meramec is the J. C. Potter No. 1, Wm. Helpingstein, Sec. 11, T. 1 N., R. 1 E., Marion Co., total depth 2240 ft. The log below the Meramec is the Gulf No. 1 Grathwohl, SW¼ SW¼ SE¼, Sec. 34, T. 1 N., R. 1 W., Washington Co., total depth 4334 ft.

of the Mississippian system—consists of a succession of alternating limestone-shale and sandstone-shale formations. The sandstone-shale units, in particular, show a great deal of lateral variation. The Chester series is in a sense transitional between the carbonate rocks of the Meramec-Osage groups and the predominantly clastic rocks of the overlying Pennsylvanian system. Because pre-Pennsylvanian erosion removed parts of the younger beds, the base of the Glen Dean limestone, a cream-colored to light-brown limestone which may be dolomitic, slightly oolitic, or cherty, was chosen as the upper horizon for the Chester isopach map (fig. 7). The Glen Dean is recognized as the limestone-shale sequence beneath the Tar Springs sandstone and above the Hardinsburg sandstone-shale formation. The base of the Chester series is the lower horizon of this isopach map.

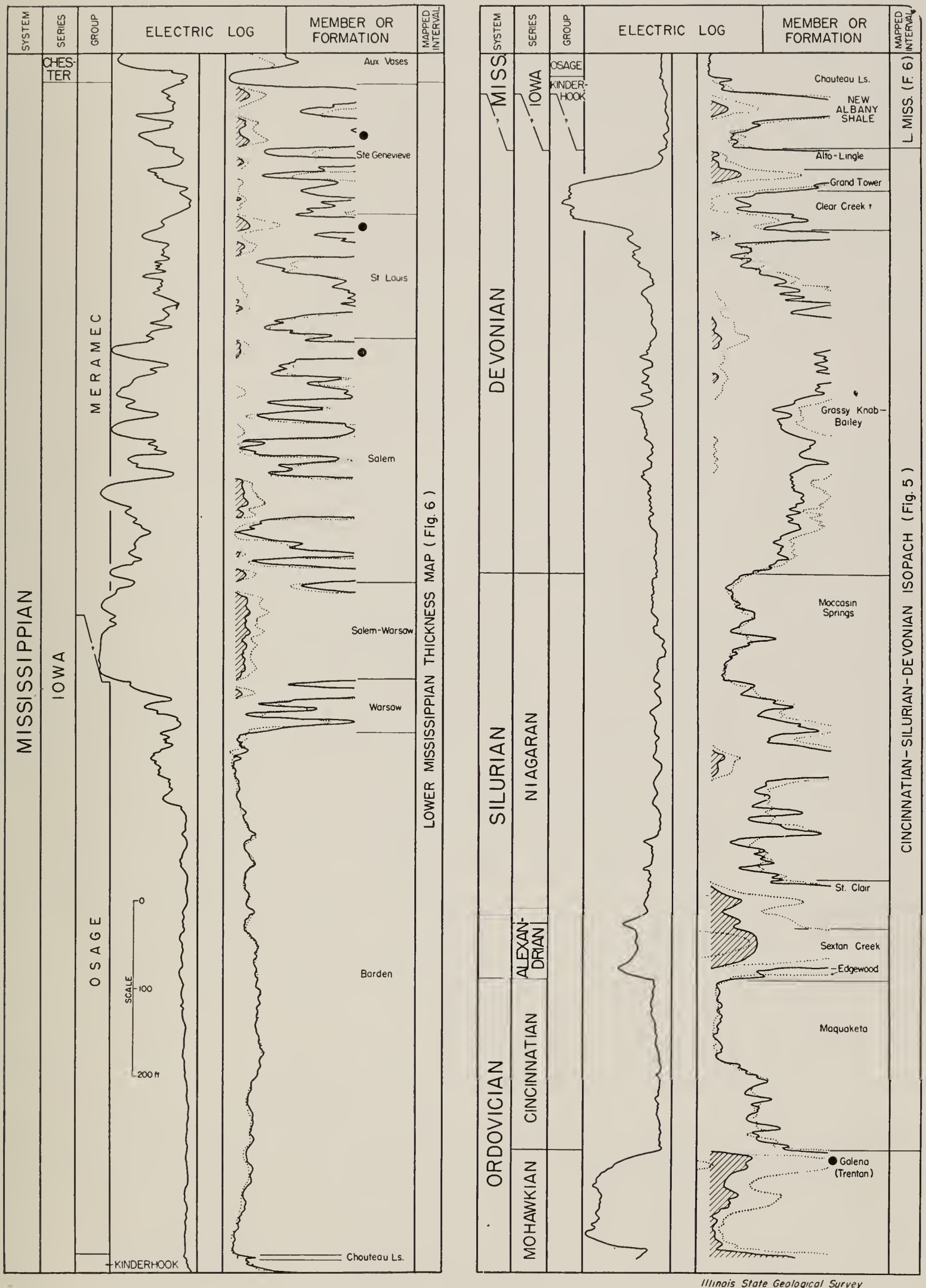

FIG. 3.—Continued.

Table 1.—Oil Field Data in the Centralia Area as of January 1, 1953

Name	Producing formation	Depth	Proved acreage	No. of wells producing Dec. 1952	1952 production	Cumulative production
Boulder			640	26	256,000	4,518,000
	Bethel	1190	520	20	187,000	
	Devonian	2630	440	6	95,000	
Brown, Junction City and Langewisch-Kuester			205	5	6,000	
	Pennsylvanian	610	90			
	Cypress	1660	115			
Centralia			3360	456	837,000	36,986,000
	Pennsylvanian	690	10	1		
	Cypress	1200	1400	49	369,000	13,841,000
	Bethel	1355		222		
	Devonian	2870	2500	118	352,000	21,160,000
	Trenton	3930	1400	57	158,000	1,985,000
				9 comb.		
Centralia West	Bethel	1440	90	2	4,000	374,000
Cravat	Bethel	2070	120	8	7,000	308,000
Hoffman			260	27	14,000	665,000
	Cypress	1190	120	6		
	Bethel	1320	180	21		
Irvington			1000	76	152,000	5,204,000
	Cypress	1380	100	2		
	Bethel	1535	950	64		
	Devonian	3090	160	3		
				7 comb.		
Odin	Cypress	1750	290	28	329,000	1,093,000
Raccoon Lake			400	33	660,000	1,374,000
	Cypress	1625	190	18		
	Lower Ohara	1885	20	0		
	Rosiclare	1930	100	1		
	McClosky	1950	260	2		
	Devonian	3260	300	1		
Salem			9600	1936	3,080,000	222,394,000
	Bethel	1780		377		
	Renault			0		
	Aux Vases	1825		0		
	Rosiclare	1950	9600	5		
	McClosky	1990		300		
	St. Louis	2100		8		
	Salem	2160		20		
	Devonian	3440	5680	183	223,000	36,020,000
	Trenton	4500	2160	40	116,000	3,820,000
				1003 comb.		
Sandoval			480	16	39,000	5,634,000
	Bethel	1540	460	0	0	2,705,000
	Devonian	2920	390	16	39,000	2,929,000
Sandoval West	Cypress	1420	10	1	2,000	21,000
Shattuc			320	24	49,000	373,000
	Cypress	1280	160	9		
	Bethel	1420	10	1		
	Trenton	4020	220	14	27,000	227,000
Wamac	"Petro"	720	250	11	9,000	669,000
Total	. . . .	. . .	17,025	2,649	5,444,000	279,613,000

The Iowa series of the Mississippian system (Butts, 1925; Payne, 1940; Folk and Swann, 1946) is characterized by a predominantly carbonate section in its upper part and a shale section in its lower part. The formation boundaries and the correlations of some of the formations are somewhat uncertain. The New Albany black shale, which is at the base of the Iowa series, is commonly considered part Iowa and part Devonian. The Iowa isopach (fig. 6) includes the interval from the base of the black shale to the top of the series.

The Devonian system (Caylor, 1944; Weller, 1944; Workman, 1944) is characterized by slightly sandy limestones and dolomites. These strata are underlain by the silty and cherty dolomites of the Niagaran series of the Silurian system (Lowenstam, 1949, 1950). In subsurface work it is difficult to locate formation boundaries within the Devonian or the contact of the Devonian with the Niagaran strata. For this reason the Devonian and Silurian diastrophisms are studied as a unit. The Niagaran series is underlain by the relatively thin limestones and dolomites of the Alexandrian series.

Ordovician formations commonly penetrated by wells in the Centralia area are the Maquoketa (Cincinnatian) shale-and-limestone formation and the Trenton (Mohawkian) limestone (Du Bois, 1945). Earlier formations are described by Du Bois (1945) and Workman and Bell (1948).

STRUCTURE

Two structure maps are presented with this report; the first (fig. 4) represents the base of the "Barlow" limestone (Golconda formation), and the second (fig. 10) represents the base of the Shoal Creek limestone (McLeansboro group). These maps differ both qualitatively and quantitatively because structural forces between Barlow and Shoal Creek times differed in character and intensity from those which have operated since Shoal Creek deposition.

REGIONAL WARPING

Most stratigraphic units thicken and dip toward the southeast, indicating that downwarping in this direction was the dominant structural movement. The regional dip of all horizons increases abruptly at the DuQuoin monocline. West of the monocline McLeansboro strata dip an average of 5 feet per mile to the southeast. East of the monocline these same beds dip 15 feet per mile to the southeast. Chester horizons dip 25 feet per mile west of the monocline and 55 feet per mile on the east side.

FOLDING

Folding in most of Illinois is of the plains type, that is, the rocks are only mildly deformed. In this report, folding in the Centralia area is differentiated as initial, tectonic, compactional, and solution. Two geometrical and genetic types of tectonic fold are recognized, parallel and supratenuous. Compactional folds, all of which are supratenuous, are divided into folds over buried reefs, folds over buried sand bodies, folds over buried tectonic structures, and folds over buried topography.

Initial folds are relief features of a bedding plane that have been caused by local differences in deposition or erosion or both. In the Centralia area, reefs, sand bars, and topographic features of unconformities are the principal features whose surfaces departed from horizonal at the time of deposition. The marker horizons used in this report are believed to be relatively free from the direct effects of such features. The indirect effects impressed upon overlying beds through compaction are discussed below.

Tectonic folds are formed by deformational stresses set up in the basement complex, the overlying sedimentary strata, or both. It is not the purpose of this paper to consider the nature or cause of these forces, but it is important to show that such forces have operated and to differentiate as far as possible folding of this character from that caused by other factors. Evidence for such forces is found in parallel

Fig. 4.—Structure map of base of Barlow limestone (basal Golconda, Chester series).

folds and in supratenuous folds whose closure and rate of thinning vary abruptly with depth.

Parallel folds are those which exhibit the same amount of deformation on all horizons; as the name implies, the beds are parallel. Folding of this character in Illinois has generally been caused by tectonic forces. The Wamac and Junction City domes may be structures of this type; the supporting evidence is discussed below.

Supratenuous folds are folds whose closure is greater on the deeper bed. As a result strata are thinner over the fold than in the surrounding area. This descriptive term includes not only tectonic folds that underwent more than one episode of folding, but also the nontectonic compactional folds described below. It is not always possible to differentiate between supratenuous folds formed by tectonic forces and those formed by compactional forces, al-

though abrupt changes in the amount of closure with depth suggest recurrent tectonic deformation. Many supratenuous folds in southern Illinois probably have both recurrent tectonic and compactional elements. The Shattuc dome, the Centralia and Salem anticlines, and possibly some other structures are supratenuous folds formed largely by recurrent tectonic folding, although the thinning of the lower Pennsylvanian rocks over the Centralia structure (fig. 8) surely includes some compactional component.

Compactional folds are caused by differential subsidence of the deformed stratum while the underlying rocks are compressed over and around less compressible rock masses. A coral reef, a sand body, a buried structure, or buried topography may produce such inequalities in compaction.

Compaction over buried reefs has recently received considerable attention in Illinois because of its importance in trapping oil in the overlying sediments as well as in the reef itself. Folds due to the draping of sediments over buried reefs are supratenuous. They differ from tectonic folds in that there is little or no closure beneath the reef, there is abnormal thickening in the strata that contain the reef, and there is a progressive decrease in closure and thinning with height above the reef. Boulder, Raccoon Lake, and Sandoval pools produce oil from structures of this type.

Compaction over sand bodies enclosed in a shale layer is similar to that over a buried reef. As the thickness of a sand lens is commonly much less than the relief on a reef, the closure at a given distance above a sand body is therefore less than at the same distance above a reef, and it disappears within a shorter distance upward. In general the closure on the next higher marker above Chester sand bodies is approximately one-half the thickness of the closure on the sand (Swann, personal communication). It is likely that some Pennsylvanian and Chester structures are caused by compaction over sand bodies. None is named, but the Barlow structure near Boulder and Sandoval fields is probably influenced by compaction over lower Chester sandstones.

Compaction over a buried tectonic structure is similar to that over a reef. An important difference is that folding extends indefinitely downward instead of terminating as it does at the reef level. Folding over pre-existing structures is most significant if deposition of a highly compactible rock such as shale or coal attended the period of folding so that the compactible rock is thicker over basins than over domes and anticlines. Differential compaction proportionate to bed thickness allows the overlying beds to subside more over structural lows. In many, or perhaps most, cases, recurrent tectonic folding masks any compactional folding between episodes of tectonic folding. On the other hand, compaction folding probably renders a structure more susceptible to later tectonic deformation.

No place is known in Illinois where the structure of a younger bed can be proved to be caused entirely by compaction folding over a buried structure. It would be a natural mistake to group structures of this type with those formed by recurrent tectonic folding. It is suggested here that the present structure of McLeansboro horizons may be due in large part to the reflection of earlier tectonic movements.

Compaction over buried topography, except for hills on the basement complex (Workman and Bell, 1948, p. 2043) and reefs, as discussed above, seems to have little quantitative importance in Illinois. The size of structures produced by compaction over topographic features depends upon the amount of relief at an unconformity and upon the relative compressibility of the rocks above and beneath the unconformity. Where the overlying rocks are more compactible, the impression of topography is positive; if the rocks beneath the unconformity are more compressible, the impression is negative. It is obvious that where there is little relief or where the strata on either side of the unconformity are of the same order of compressibility, folding will be negligible.

The topographic relief that developed on pre-Cambrian, pre-St. Peter, and pre-Pennsylvanian surfaces is sufficient to be impressed upon the overlying strata. The pre-

Cambrian surface has affected structure in Wisconsin (Thwaites, 1931) and in western Illinois (Workman and Bell, 1948, p. 2043), but its direct influence, if any, in the Centralia area is limited to strata not yet reached by drilling.

The St. Peter and Platteville formations show no evidence of compactional structures in their outcrop area (Templeton, personal communication), and it seems unlikely that any structure in the Centralia area can be attributed to the reflection of relief on the pre-St. Peter surface.

The Mississippian-Pennsylvanian unconformity in southern Illinois, including the Centralia area, has been studied by Siever (1951). He finds that the land surface of this area during pre-Pennsylvanian times was a peneplain with entrenched stream channels. The Chester bedrock surface contains a high proportion of fine-grained highly compactible shales; the overlying Pennsylvanian sediments are relatively less compactible sandstone and siltstone. The structural impression of this surface would be negative with low, linear, and sinuous high structures over buried channels. Siever (1951, p. 578) states that the effects of compaction on this surface would have been slight above 200-300 feet from the surface of the unconformity. The high in secs. 29-32, T. 2 N., R. 1 W. (see fig. 10), appears to be such a reversed or negative impression formed by the compaction of the Chester bedrock in which a channel was filled with Pennsylvanian sandstone. Folding of this type and folding due to compaction over lower Pennsylvanian sand bodies are best known to the oilman for producing highs that can be mapped on coal beds but that do not exist in the underlying Chester oil zones.

Solution folds are caused by the differential subsidence of a stratum as solution removes some of the underlying strata. Folds of this type are known in northwestern and southeastern Illinois (Grogan, 1949; Willman, 1945). The presence of stylolites testifies to the prevalence of solution everywhere in Illinois. Yet there is no evidence to suggest that solution folding is significant within the Centralia area.

From a structural point of view, supratenuous folds due to tectonic movements have the greatest relief and largest area under closure and are thus the most important in the Centralia area. Parallel folds are not known with certainty within the area, though Wamac dome may be of this type. Three reefs are within the area mapped and another is nearby; each has a closure of about 120 feet on the base of the New Albany shale and an area of about one square mile. Other structures caused by differential compaction are small; they occur commonly in combinations with other types of folding.

From an economic viewpoint as well, supratenuous folds due to recurrent tectonic folding are by far the most important. Both the Centralia and Salem fields produce oil from structures of this type. Next in importance are the reef structures, which yield good oil production from Niagaran reefs and overlying Mississippian "sands." Structures caused by compaction of shale above sand lenses, pre-existing structures, and topography may have served as temporary oil traps during Mississippian times until early Pennsylvanian tectonic movement increased the capacity of the major structures. Post-Pennsylvanian parallel folds in Illinois are normally dry.

FAULTING

One fault zone is known from subsurface data within the Centralia area, although there are no surface indications. It strikes roughly north-south, parallel to and about a mile east of the crest of the DuQuoin monocline. The northern part of the zone was worked out by Bell (1927) from mine records. In the Glen Ridge mine under Junction City, four faults were encountered within 500 feet along the same entry (sec. 30, T. 2 N., R. 1 E.). A fifth fault lies 750 feet to the west beyond the limits of the entry. Subsurface data, particularly on the base of the Shoal Creek limestone, suggest that this zone of faulting extends at least as far south as sec. 6, T. 1 S., R. 1 E.

The principal fault of the complex extends from the town of Sandoval, sec. 18,

T. 2 N., R. 1 E., to sec. 6, T. 1 S., R. 1 E., and possibly farther south. Its downthrown side is on the west. The exact displacement is not known, although subsurface mapping suggests that displacement reaches 160-200 feet in sec. 6, T. 1 S., R. 1 E., that it diminishes from this point to a minimum, and then increases to 140 feet in sec. 7, T. 1 N., R. 1 E. From this point the displacement decreases to the north and is last observed in the mine of the Sandoval and Chicago Coal Company beneath Sandoval.

A second fault parallels the main fault about 1000 feet to the west in secs. 18, 19, and 30, T. 2 N., R. 1 E. It is downthrown on the east with a displacement of three feet near the south line of section 30 and of eight feet near the north line of the same section. It thus forms an asymmetric graben with the main fault. Three other faults with displacements of a few feet fracture the graben floor.

The faults in this area show that shearing stresses were set up after most or all of the folding took place and that the major relief of the stresses was upward on the east side, opposed to the easterly dip of the DuQuoin monocline.

STRUCTURAL HISTORY

Interpretation of the structural history of the Centralia area is based on isopach and structure maps. A structure map is primarily a record of the deformation undergone by the mapped horizon since its deposition. An isopach or thickness map includes the record of the deformation of the bottom of the mapped strata that occurred before the top was deposited. A series of such maps covering completely the available stratigraphic section of any area, the top of one mapped interval being the base of the next higher, and concluding with the structure map of the highest key bed, should thus record the decipherable structural history of that area. Figures 5 through 10 form such a series.

Actually structural deformation is only one of a number of factors determining the thickness of a stratigraphic unit which is known on an isopach map. Structural deformation is also only one, although usually the greatest, of several factors that influence a structure map. The disturbing influences of the other factors must be recognized and taken into account in order to get an undistorted picture of the structural evolution of the area.

The original relief, either topographic or sedimentational, of a horizon may be a very important component of either a structure or isopach map based on that horizon. In order to isolate structural factors, the key horizons used in this report were chosen in the belief that they originally had essentially no topographic relief and little sedimentary deviation from horizontal. Suspected departures from the ideal conditions of original horizontality are noted in the individual sections below.

Any facies change involving sediments of different compactibility will, through differential compaction, lead to variations in thickness. Care must be taken to differentiate such facies-induced patterns from tectonic patterns. The most obvious changes involving reefs and lenticular sands are noted, but other more subtle variations may have been undetected. As implied in the earlier discussion of compaction folds over reefs and sand bodies, a relatively noncompactible body causes not only a thick spot in the stratigraphic interval containing it, but thin spots in the overlying strata which were deposited while the differential compaction was taking place.

Simple gravitational compaction, in reducing proportionally both the thin and thick portions of a stratigraphic unit, also reduces the amount of relief; not only are maxima and minima decreased, but also the differences between them. Thus the closure on an isopach "thin" is in general less than the structural closure on the lower boundary when the upper marker bed was deposited, and it is less by an amount proportional to the amount of compaction. It is evident that the process which reduces the relief at one level is the same process which impresses structural patterns on still higher horizons, for the changes are simply transferred to the thickness of the interval during which the compaction took place and appear

on the map as compaction folds over buried structures.

Though certain other factors such as interstratal solution and igneous intrusion may affect isopach data, they were probably either lacking or not significant in the Centralia area.

TRENTON AND EARLIER DEFORMATION

As only one well within the Centralia area extends to the St. Peter formation (Chazyan)—The Texas Company, No. 21, Edward Tate, in sec. 5, T. 1 N., R. 2 E.—no evidence can be assembled to show pre-Maquoketa structural movements in this area.

Studies in Wisconsin by Thwaites (1931) and in northern Illinois by Payne (Willman and Payne, 1942) and Templeton (personal communication) indicate considerable relief on the pre-Cambrian surface and folding of the upper pre-Cambrian formations. Minor folding occurred during Galesville (late Cambrian), New Richmond and Shakopee (early Ordovician), and St. Peter (early middle Ordovician) times. The pre-St. Peter erosional interval was accompanied by uplift of several structures found in the Shakopee dolomite but not in the overlying St. Peter sandstone. Pre-St. Peter faulting occurred locally in northern Illinois. There was minor folding during Black River and Trenton times (late middle Ordovician), and the Trenton closed with regional uplift and warping.

The Centralia area no doubt experienced similar deformation during these times, and the Centralia anticline and other anticlinal features formed by recurrent tectonic folding were probably in existence before Trenton time.

SILURIAN-DEVONIAN DEFORMATION

Figure 5, an isopach map showing the interval from the base of the Maquoketa shale to the base of the New Albany shale, shows the effect of Silurian and Devonian diastrophism. The Maquoketa shale, which is quite uniform in thickness in the Centralia area, is included here with the Silurian-Devonian because some well records do not report the depth of the base of the Silurian but do report the base of the Maquoketa. The lower portion of the New Albany black shale is believed to be Devonian, but for practical reasons the top of the isopach interval is the base of the formation rather than the unidentified Devonian-Mississippian boundary.

As control data are limited to oil pool areas, regional trends are not well defined, thus part of the thinning of strata over anticlinal areas is suggested rather than proved. In general, Silurian-Devonian deformation consisted of subsidence and downwarping toward the southeast. The rocks thicken to the southeast at an average rate of about 12 feet per mile.

There is some thinning of strata over the Centralia and Salem pool areas. Over the Centralia pool the strata range in thickness from 1080 to 1150 feet. The axis of thinning corresponds to the structural axis of the anticline. Over the Salem pool the thickness ranges from 1160 feet in sec. 20, T. 2 N., R. 2 E. (center SE¼ SW¼), 2120 feet elsewhere in the pool. Correspondence of structural trends to thickness over the Salem pool is rather poor.

The thinning of an interval between two beds can be attributed to differential compaction and other factors as well as to tectonic folding, yet the persistent thinning over the Centralia structure of all intervals studied suggests tectonic folding. The small amount of shale in the middle Ordovician rocks of the region was not conducive to the compactional impression of St. Peter structure on these higher beds or of topography buried at the base of the St. Peter. It is theoretically possible that shales in some of the Cambrian formations may extend the influence of Cambrian and earlier structures to the overlying beds. But any thinning due to this factor is likely to be only a small part of the total thinning of the interval.

The Devonian-Silurian rocks are 1166 feet thick in a Trenton test on top of the Boulder dome and 1319 feet slightly east of

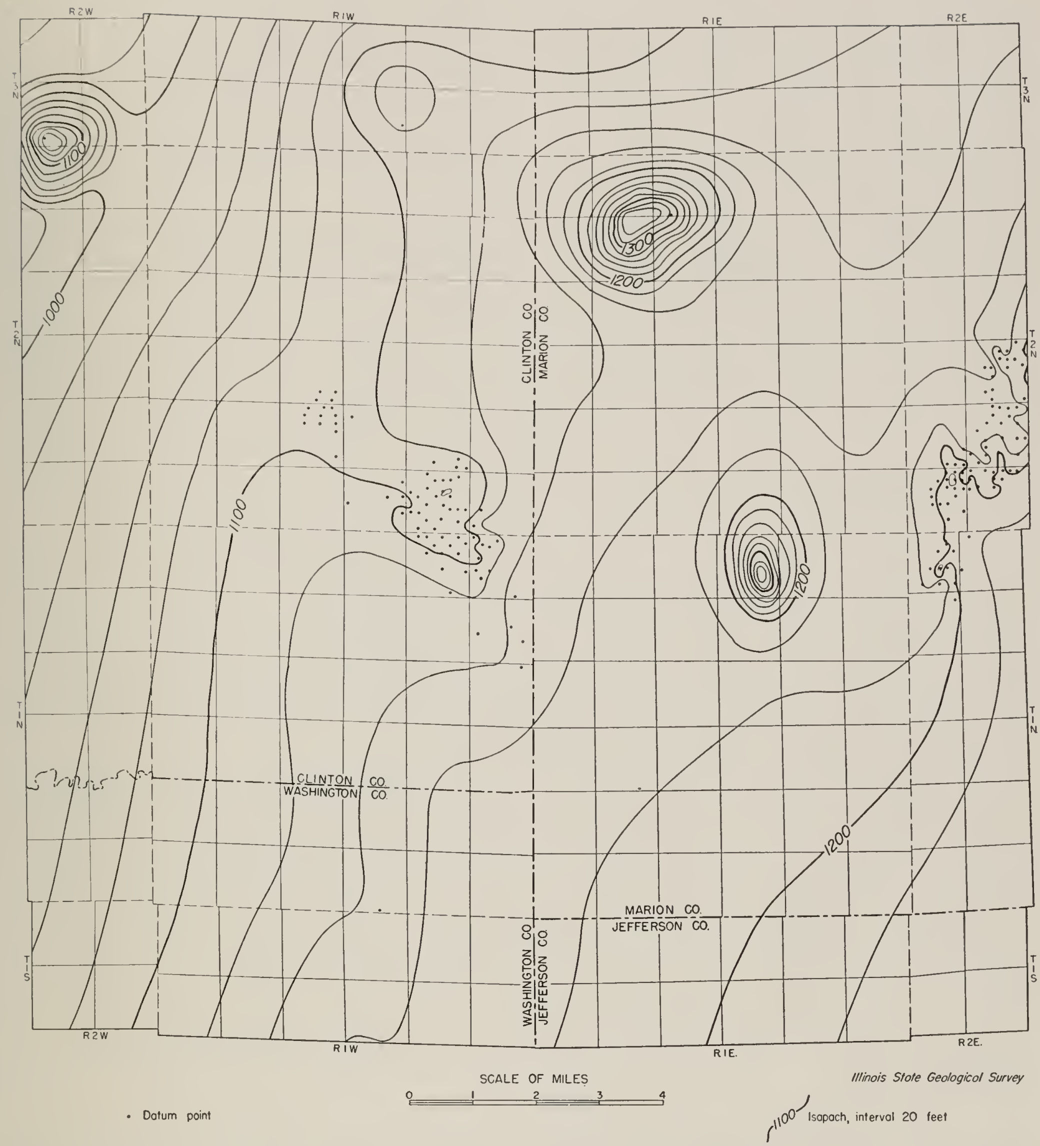

FIG. 5.—Isopach map showing thickness of Cincinnatian, Silurian, and Devonian strata (top of Trenton to base of New Albany).

the crest of Sandoval dome. This is 100 to 200 feet more than the expected regional thickness for these areas and is consistent with the interpretation of the Boulder and Sandoval structures as Niagaran reefs. The electric and lithologic logs of the wells in the Boulder and Sandoval areas indicate thick Silurian reef sections in this interval. The Devonian structure and the thinning of the lower Mississippian strata over the Raccoon Lake dome are similar to the structure and thinning over the Boulder and Sandoval domes. Cores from the Raccoon Lake area contain Silurian reef fossils (Wayne F. Meents, personal communication).

The slightly thickened Silurian-Devonian interval in the well in the eastern part of sec. 34, T. 3 N., R. 8 E., suggests a reef, but the electric log shows no trace of reef lithologies. Moreover regional control data are scanty. An interpretation showing 40

feet more of regional thickness in this area would nullify this anomaly but intensify the thinning over Centralia and Salem pools. The interpretation shown in figure 5 appears at this time to be more justified.

In general, Silurian and Devonian diastrophism consisted of subsidence accompanied by gentle downwarping to the southeast and by minor folding. During Niagaran times, marine organisms established colonies and built reefs—mounds of organic material—which have been reflected as domes and as areas of decreased deposition since Niagaran times.

LOWER MISSISSIPPIAN DEFORMATION

(Iowa)

The time represented by the lower Mississippian isopach map (fig. 6) includes a little late Devonian as well as the Kinderhook, Osage, and Meramec epochs of the Mississippian period. If allowance is made for the compaction of Kinderhook and Osage shales, this map shows the structure which existed on the base of the New Albany shale (top of the Devonian limestone) at the beginning of Chester time.

The formations thicken to the southeast at the rate of about 20 feet per mile. Their thickness is 1220 feet near the northwest corner of the mapped area and 1520 feet near the southeast corner. There is no change in the rate of thickening on either side of the DuQuoin monocline. The regional trend during this period was subsidence accompanied by mild downwarping to the southeast, with the result that by early Chester time the lower Mississippian beds dipped gently and with fair uniformity to the southeast.

A conspicuous feature of the lower Mississippian isopach map is the belt of thinning which strikes northwest-southeast, normal to the regional strike, in the present position of the Centralia anticline. Where best developed it is 70 feet thinner than the regional norm. Less conspicuous is a broad belt of thinning in the Salem and Odin pool areas. In the vicinity of Odin there are only four datum points in 16 square miles, but they suggest that the structure which caused the thinning was an elongate nose with an axis of uplift nearly parallel to that of the Centralia structure, with its highest points 40 to 60 feet above the beds on either side.

Also prominent is the thinning of lower Mississippian strata over the domes of the Boulder, Raccoon Lake, and Sandoval oil fields, caused almost entirely by the differential deposition of lower Mississippian rocks as compaction of the circum-reef Silurian sediments emphasized the protruding reef core. Each dome covers about a square mile. The strata thin 60 feet over Boulder dome, 100 feet over Raccoon Lake dome, and 50 feet over Sandoval dome.

The thinning of the strata in secs. 34 and 35, T. 3 N., R. 1 W., shows in figure 6 and all subsequent maps. The fact that thinning occurs over the slightly thickened Devonian-Silurian interval in section 34 strengthens the possibility of Silurian reef conditions in this area.

The over-all picture of early Mississippian deformation is one of subsidence and tilting to the southeast with minor folding. The organic reefs formed during Niagaran times continued to influence both the structure and thickness of the overlying beds as Niagaran sediments around the reefs were differentially compacted.

UPPER MISSISSIPPIAN DEFORMATION

(Chester)

Figure 7 is an isopach map of the pre-Glen Dean formations of the Chester series. An isopach map designed to show Chester structural movement must employ as its upper boundary a depositional horizon within the Chester rather than the upper surface of the series, because that surface was not a marine plain but a land surface with as much as 200 feet of relief, and its age varies significantly from spot to spot even within as small a region as the Centralia area. In addition, it is difficult to determine the top of the Chester, especially where its sandstones are in contact with similar Pennsyl-

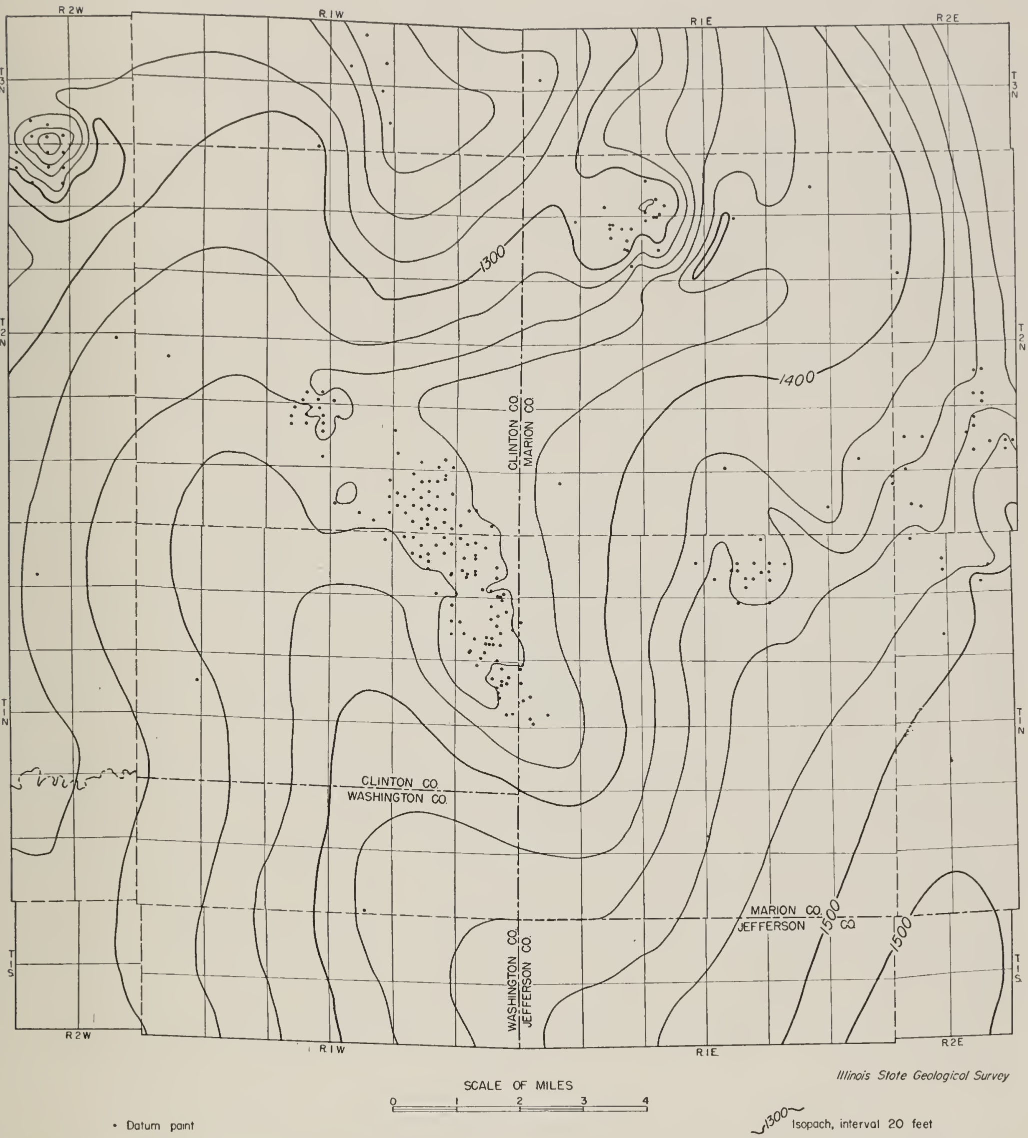

FIG. 6.—Isopach map showing thickness of lower Mississippian or Iowa strata (base of New Albany to top of Ste. Genevieve).

vanian sediments. The deformation shown on figure 7 is probably similar to that which occurred during Mississippian deposition.

Because the Chester beds include many lenticular sandstones, the isopach map of the interval is complex, and its structural evaluation is more difficult and less reliable than that of most of the other maps studied. The pre-Glen Dean formations of the Chester series thicken to the southeast about three feet per mile, from about 420 feet in the northwest corner of the area mapped to about 500 feet near the southeast corner.

The Centralia and Salem anticlines show between 30 and 50 feet of thinning of the pre-Glen Dean Chester beds. In each the axis of uplift is similar to that of the present structure, although the random trends of the Chester sand bodies disguise the structural grain. The thickening in sec. 35, T. 2 N., R. 1 W., suggests a pre-Chester valley system. Control is lacking in section 13 and

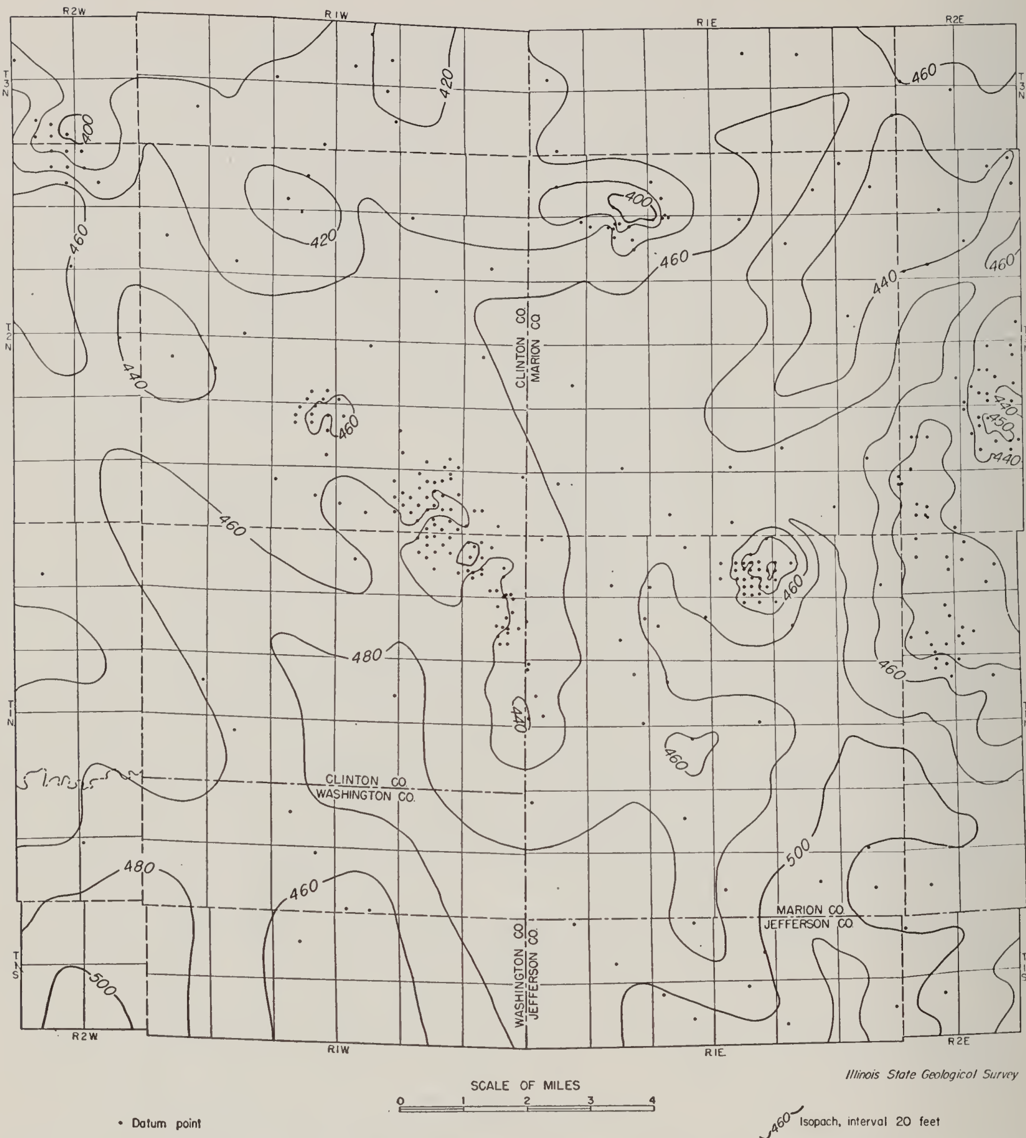

FIG. 7.—Isopach map showing thickness of upper Mississippian or Chester strata (top of Ste. Genevieve to base of Glen Dean).

the west half of sec. 12, T. 1 N., R. 1 W., because pre-Pennsylvanian erosion removed the Glen Dean formation.

The Boulder, Raccoon Lake, and Sandoval reef structures show the effects of differential deposition as compaction of the underlying shales and circum-reef sediments continued. The present thinning of the Chester over these structures is about 60 feet. It was probably of the order of 90-100 feet prior to compaction.

Thickening of Chester strata over sand lenses, as at Shattuc and near Tonti, may have been as influential in producing the complexity shown on figure 7 as was pre-Chester erosion in such other places as the Centralia anticline area. Both factors affected the thickness of Chester beds, which makes the interpretation of this interval difficult.

The dominant structural movement during Chester times was further subsidence

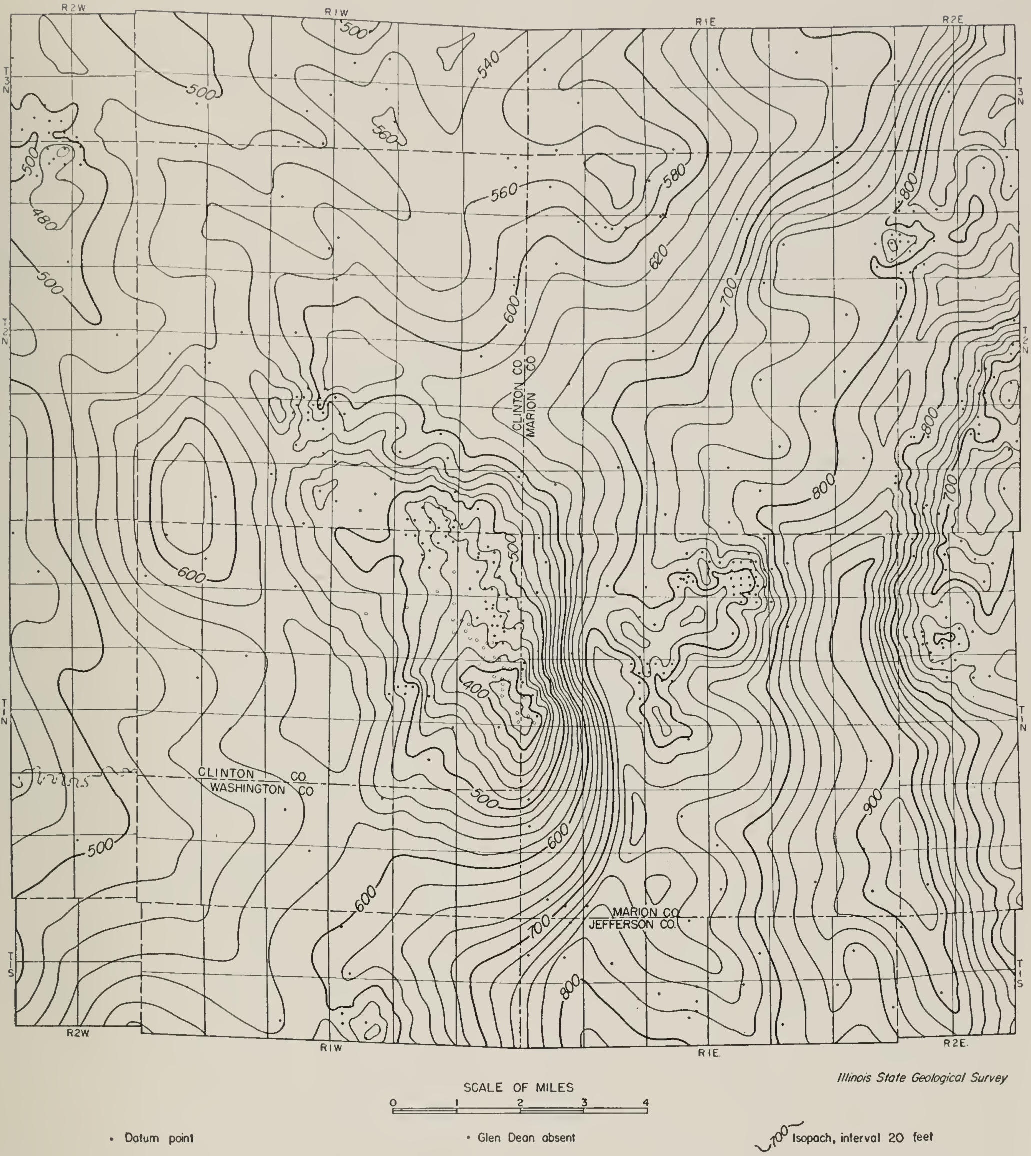

FIG. 8.—Isopach map showing thickness of lower Pennsylvanian and post-Hardinsburg Mississippian strata (base of Glen Dean to coal No. 4).

and tilting towards the southeast. The magnitude of the thinning (about 15 percent of the total thickness) over the two major tectonic axes, Centralia and Salem (the latter clearly evident for the first time), shows that this is the first period of significant deformation in the Centralia area. The prominence of shales in the Osage and Chester series and the progressive compaction of Silurian circum-reef sediments still made the Silurian reef structures important determinants of deposition in Chester time, and indeed their influence was transmitted to all overlying beds.

EARLY PENNSYLVANIAN DEFORMATION

(Pre-No. 4 Coal)

Figure 8 is an isopach map of the interval between the base of the Glen Dean formation and No. 4 coal. The No. 4 coal is

below the middle of the Carbondale group and is equivalent in age to beds in the lower part of the Marmaton group of the Mid-continent region (Cooper, 1946, p. 16). Reasons have been given for employing the base of the Glen Dean formation rather than the base of the Pennsylvanian system as the lower datum horizon of this map. The No. 4 coal was employed instead of the base of the Carbondale because it is more readily recognized on electric and sample logs.

Figure 8 includes late Chester and early Pennsylvanian time. Quantitatively, deformation during late Chester and early Carbondale times was relatively unimportant; hence the deformation shown is largely that of the post-Chester hiatus and Caseyville-Tradewater time. In a regional study of the unconformity at the base of the Pennsylvanian, Siever (1951, p. 570) achieved good results in separating deformation during the post-Chester hiatus from that attending early Pennsylvanian deposition in southern Illinois. This is not possible in a study of a small area in which single pre-Pennsylvanian topographic features may occupy large portions of the area and hide structural effects.

The thickness shown in figure 8 ranges from 460 feet along the southern part of the western margin to 920 feet near the southeast corner of the mapped area. The thickening is 16 feet per mile west of the DuQuoin monocline and 40 feet per mile across and east of this structure. Although the Mississippian-Pennsylvanian unconformity (Siever, 1951) shows that southern Illinois underwent a major emergence between Chester and Pennsylvanian times, the thickening revealed on this map shows that subsidence and downwarping to the southeast was still the dominant structural movement over the whole of late Chester and early Pennsylvanian time.

The difference in the rate of thickening of strata on either side of the DuQuoin monocline and the relatively greater rate of eastward thickening over the area shows that the monocline came into existence during the time represented by figure 8. The proximity of an erosion channel, the Centralia anticlinal axis, and the DuQuoin monoclinal axis, makes it difficult to determine from data in the Centralia area alone whether or not monoclinal flexing began prior to Pennsylvanian deposition. Siever (1951, p. 572), working with a larger area, concludes that it began during Caseyville deposition, as "the Chester beds show little or no thinning. The areal geologic map of the pre-Pennsylvanian surface and the upper Chester isopach map show no influence of structure in this area. The Chester beds show no difference in types of sediments on either side of the flexure, but Pennsylvanian beds show the influence of a rising structure on the rates of sedimentation. The thickest Pennsylvanian deposits are east of the monocline; these beds thin drastically on the crest of the structure and thicken again west of the monocline but not so much as on the east."

The early Pennsylvanian strata thin 240 feet over the Centralia structure and 200 feet over the Salem structure. This thinning must be attributed to tectonic folding. Over the crest of the southern part of the Centralia anticline, the Hardinsburg and younger Chester beds were removed by erosion, and basal Pennsylvanian beds lie directly on the Golconda formation. A mile east of the crest the basal Pennsylvanian beds lie on the Palestine or Menard formations; the same is true to the southwest but at a distance of three or four miles instead of one. The thickness of Chester beds removed over the crest of the Centralia structure was about 250 feet. It seems most logical to account for this inlier as being at least partly due to tectonic folding during the post-Mississippian, pre-Pennsylvanian hiatus, rather than to attribute it entirely to pre-Pennsylvanian topography. On the other hand, the basal Pennsylvanian surface is shown as essentially parallel to Chester depositional surfaces in cross sections across the northern part of Salem field; this fact suggests that there was no appreciable folding of the Salem anticline before Pennsylvanian deposition began in the area.

The thinning of strata at Odin (sec. 12, T. 2 N., R. 1 E.), Brown (sec. 16, T. 1 N., R. 1 E.), and Shattuc (sec. 28, T.

2 N., R. 1 W.) oil fields may be due to tectonic folding. In each case the data are not adequate to permit a definite conclusion.

The Raccoon Lake and Sandoval reef domes show thinning of 60 to 100 feet. The thinning over the Boulder dome is only 40 to 80 feet, possibly because Boulder dome is updip and buried beneath a smaller amount of sediments.

The thickening in sec. 31, T. 2 N., R. 1 W., and adjoining sections is believed to represent a pre-Pennsylvanian valley cut into the Chester bedrock surface and later filled with Pennsylvanian sandstones and siltstones. The thickening in the northeast quarter of sec. 28, T. 2 N., R. 1 W., possibly represents the filling of another part of this drainage system.

Mississippian deposition ended with a major emergence of the land in southern Illinois (Siever, 1951). This emergence was attended or followed by some tectonic folding during which the LaSalle, Centralia, and some other Illinois structures were partially deformed, though there was yet little or no movement on the DuQuoin or Salem structures. The emergence lasted long enough to allow regional bevelling by erosion. A short time before Pennsylvanian deposition this land surface was rejuvenated and deep channels were incised in it.

Pennsylvanian deposition began in southern Illinois somewhat later than in areas to the southeast and southwest. This deposition was accompanied by downwarping towards a point in southeastern Wayne County, monoclinal flexing along the DuQuoin axis, and major tectonic folding. By the beginning of Carbondale time the period of intense deformation had ended and the present structure of the Centralia area, exclusive of faulting, was essentially completed.

UPPER PENNSYLVANIAN DEFORMATION

(Post-No. 4 Coal, Pre-Shoal Creek Limestone)

Figure 9 is an isopach map of the interval from the No. 4 coal to the base of the Shoal Creek limestone. This interval covers most of the deformation which occurred during Carbondale and McLeansboro times in the Centralia area. It corresponds to the upper half of the Des Moines and the pre-Kansas City part of the Missouri series in the Midcontinent region (Cooper, 1946).

The interval between the No. 4 coal and the Shoal Creek limestone increases from 420 feet in the northwest corner of the mapped area to 540 feet in the southeast corner—an average rate of five feet per mile. The rate of thickening is greatest over DuQuoin monocline.

Local thinning is evident over the Boulder, Brown, Centralia, Odin, Raccoon Lake, Salem, Sandoval, and other anticlinal features in the area. It seems possible that compactional folding—the reflection of earlier Pennsylvanian movements, lower Pennsylvanian sand bodies, and Silurian reefs—is sufficient to account for the greater part of the thinning. Tectonic folding may have occurred during this time, but its effect on structure was slight.

Although thinning over the Junction City and Wamac domes appears for the first time on figure 9, Carbondale-McLeansboro tectonic folding is not necessarily indicated; drilling to older horizons is too scanty to reveal conditions at greater depths. It seems more reasonable to account for these domes by early Pennsylvanian tectonic movements and to explain the thinning of Carbondale and McLeansboro strata as compactional impression of the earlier-formed structures. This interpretation places the origin of these domes at the time of greatest deformation.

Carbondale and McLeansboro times were characterized by frequent cyclic changes in sedimentation which represented successive emergence and submergence of the area with the net balance in favor of subsidence. The Centralia area may have experienced minor tectonic folding and warping of the type shown on the isopach maps of earlier periods. If such folding occurred it was less important than the reflection of earlier deformations, because the compaction of Chester and Pennsylvanian shales kept pace

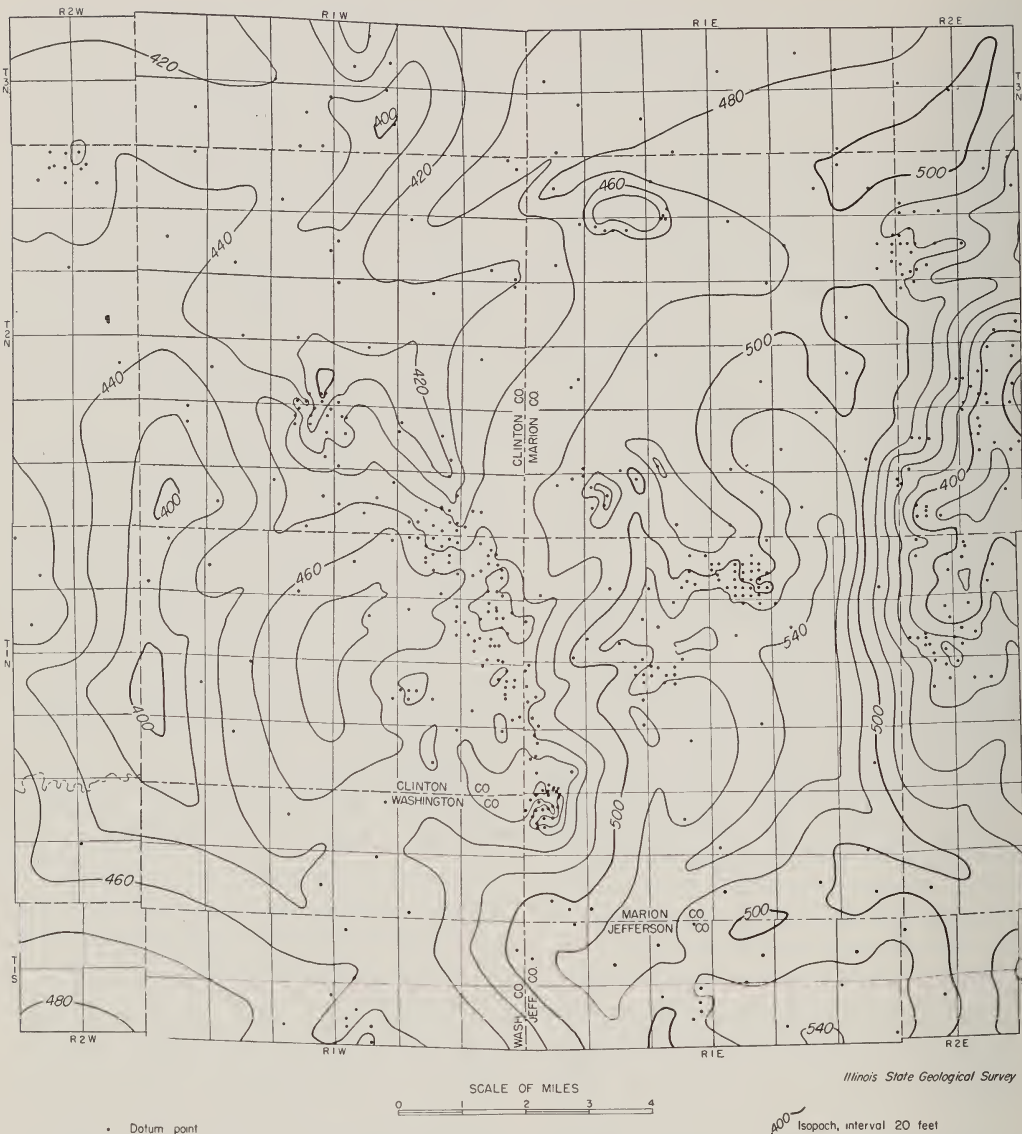

Fig. 9.—Isopach map showing thickness of Pennsylvanian strata (coal No. 4 to base of Shoal Creek).

with the subsidence of the area and the increased load of younger sediments.

POST-PENNSYLVANIAN DEFORMATION

Because the Shoal Creek limestone is the youngest marker bed common to all parts of the Centralia area, its structure (fig. 10) is best suited to show the effects of post-Pennsylvanian deformation. The Shoal Creek is 340 to 400 feet above the base of the McLeansboro group. In view of the close parallelism of all McLeansboro beds in Illinois, the deformation shown on this bed is either almost or entirely post-Pennsylvanian.

The regional dip on the Shoal Creek limestone ranges from 5 feet per mile west of the DuQuoin monocline to 15 feet per mile east of it. Dips on the flank of the monocline are as much as 250 feet per mile. This regional trend is perhaps partly due to downwarping to the southeast in post-

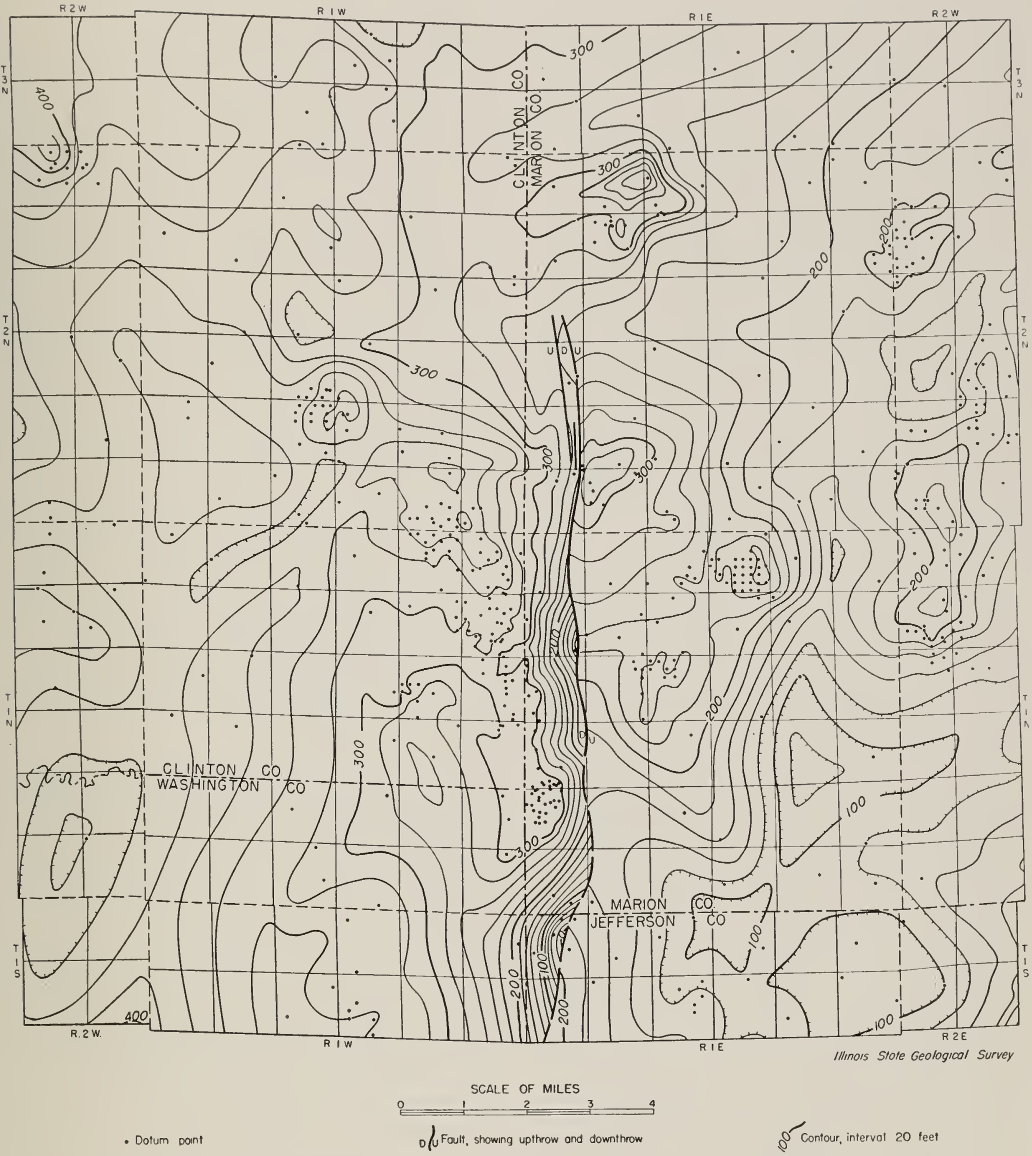

Fig. 10.—Structure map of base of Shoal Creek limestone (McLeansboro group).

Shoal Creek time but the greater part of it seems due to the reflection through post-Pennsylvanian compaction of the more intense downwarping of the area in early Pennsylvanian time.

Folding is evident on all structures discussed above as well as on structures not evident on older horizons. Folds in the Shoal Creek limestone represent nearly every type discussed above. Tectonic folding of the Shoal Creek is evident over the Fairman pool (sec. 18, T. 3 N., R. 1 E.), immediately north of the area mapped, as the closure on this horizon is nearly as great as that on Chester beds. For this reason it is almost certain that post-Shoal Creek tectonic forces competent to produce significant structures occurred within the Centralia area.

On the other hand, the Chester and Pennsylvanian rocks of the area are predominently shales and siltstones; therefore com-

pactional folding over buried structures, reefs, and sand bodies may have been sufficient to account for most of the folding evident on figure 10. The opinion here favored is that both tectonic and compactional folding of the Shoal Creek limestone occurred in the Centralia area, with compaction having a greater role than tectonic movement, both in the number of structures affected and in the amount of deformation accomplished. This opinion is supported by the fact that maps of the Shoal Creek structure and the interval between coal No. 4 and the Shoal Creek limestone are substantially the same over the Centralia and Salem anticlines as they are over Raccoon Lake reef, where there is no reasonable likelihood of tectonic movement.

The domes at the Junction City and Wamac oil pools deserve special consideration. The interpretation of these structures is limited by poor control below the Carbondale group. The lack of Chester oil production suggests that possibly there was no dome structure prior to Pennsylvanian times. The thinning of the lower Pennsylvanian beds cannot be evaluated in the absence of data on the older horizons; however, the thinning of the beds between Shoal Creek and No. 4 coal (fig. 9) over these domes is best interpreted as a reflection of tectonic doming earlier in Pennsylvanian time. This places the origin of the structures at the time of greatest deformation in the Centralia area, during the early Pennsylvanian, and attributes the structure on the Shoal Creek to compactional reflection of the earlier tectonic deformation. On this assumption the structures on the Mississippian and older beds are tectonic folds of the parallel type, whereas the Pennsylvanian structures are compactional folds over the underlying tectonic folds.

A conspicuous fault zone extends north and south along the Third Principal Meridian for a distance of 12 miles from the south margin of the mapped area. Although this feature has been described in detail, it is important to note that the upthrown side is on the east and that the faulting was due to stresses opposite in direction to stresses which caused earlier monoclinal flexing along the DuQuoin axis.

At least most of the faulting is post-Shoal Creek in age. The close parallelism of all McLeansboro beds makes faulting within that time interval very unlikely. The absence of evidence favoring pre-Pennsylvanian faulting and the relationship of the fault zone to the DuQuoin-Centralia monocline suggest that the faulting is entirely post-Pennsylvanian.

Earthquakes were felt in the area in 1920, 1937, 1946, and 1948 (Heinrich, 1937, 1946, 1948). Seismograph records located the epicenter of the 1937 earthquake as 2.2 miles northeast of Centralia. The quake was felt within an area of 8,000,000 square miles. This would seem to indicate recent movement along these faults. On the other hand, photogeologic studies, field studies (Ekblaw and Wanless, personal communication), and the records of railroad (C. H. Mottier, personal correspondence) and highway (R. H. Major, personal correspondence) maintenance crews reveal no trace of recent faulting in this area.

During or after late Pennsylvanian time, uplift of the entire Eastern Interior basin brought an end to sedimentation in the Centralia area. This uplift was attended or followed by gentle warping, minor folding, and faulting. The greater part of the folding evident on the Shoal Creek structure map is believed to have been caused by compaction of the pre-Shoal Creek sediments in post-Shoal Creek time rather than to post-Shoal Creek tectonic movement.

SUMMARY

The Centralia area is about 50 miles east of the west margin of the Eastern Interior basin. The area is bisected by the DuQuoin monocline. Its west half, structurally above the monocline, is on the shelf part of the Eastern Interior basin, while its east half is on the slopes of the deeper part, known as the Illinois basin.

The major structural features include: regional dips and thickening of strata to the southeast, monoclinal flexing down to the east and faulting down to the west along the DuQuoin monocline, and both tectonic and compactional folding. Tectonic folding was

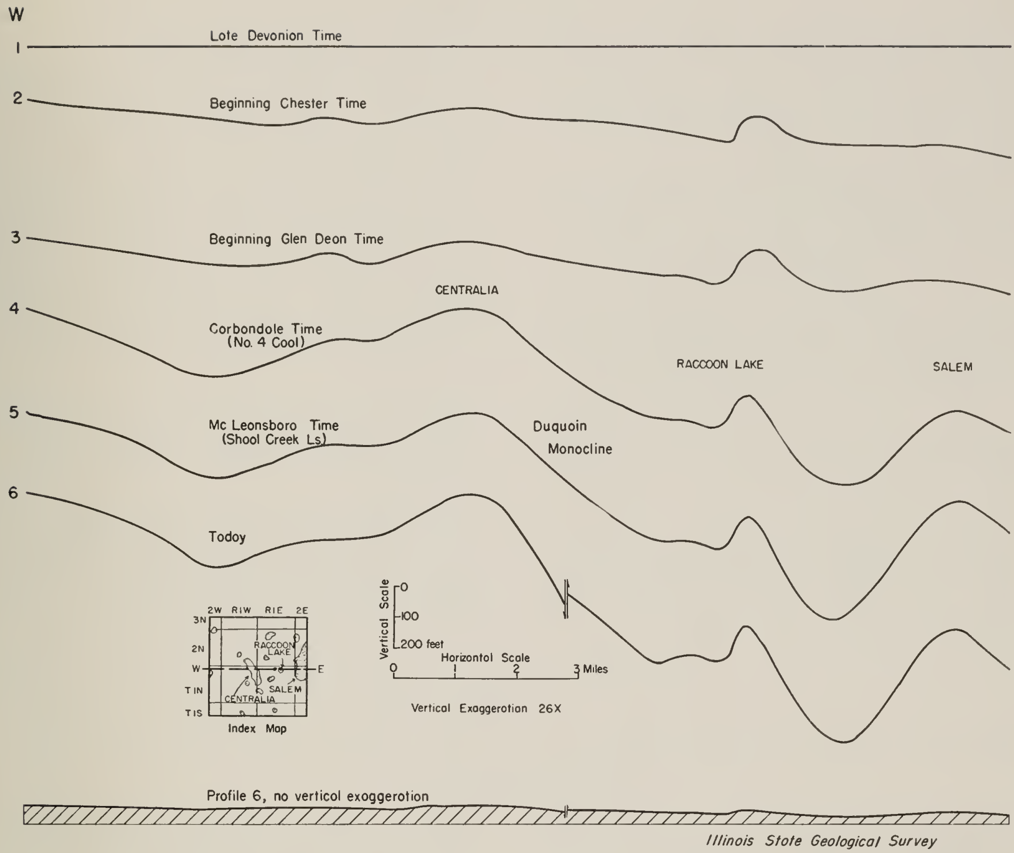

FIG. 11.—Structural profiles of several stages in the deformation of the base of the New Albany shale.

recurrent, resulting in supratenuous folds, and was responsible for the major oil pools in the Centralia area. Two small domes may be parallel folds, but there are not sufficient data to test this possibility. From a structural and economic viewpoint compactional folding is most important over buried Niagaran reefs. The reflection of buried sand bodies and buried topography has slightly modified folds of other types and may account for some minor features in the area.

The structural history of the Centralia area is shown by a series of isopach and structure maps (figs. 5 to 10) which depict, with limitations, deformation during successive intervals after Ordovician time. Salient features of the history are summarized by a series of east-west profiles (fig. 11) depicting stages in the deformation of the base of the New Albany shale, near the Devonian-Mississippian boundary. The Siluro-Devonian deformation suggested in figure 5 is not included in the condensed diagram because pre-New Albany data along the profiles are scanty, and the method of addition used in constructing the successive profiles would have included uncertainties from the earliest profile in all later ones.

In profile 1 of figure 11, the New Albany shale is assumed to have been deposited on a level surface. Profiles 2 through 5 show stages leading to the present form of the surface in profile 6. The profiles are based on the same thickness data as the maps and are therefore subject to the same limitations. Original departure, either erosional or depositional, of any datum horizon from a horizontal plane, as well as postdepositional compaction of facies of differing compressibility, introduces deviations in the thickness data. Simple nondifferential, but postdep-

ositional, compaction of the beds in a stratigraphic interval flattens the profile shown for the end of the interval, the diminution of apparent relief of any interval reappearing as apparent structural movement during the time of compaction.

Most of the following conclusions drawn from study of the maps are illustrated by the cross sections:

(1) The dominant structural movement has been subsidence and downwarping to the southeast, the east component showing on the east-west profiles of figure 11.

(2) Arching of the Centralia anticline, which began at least as early as Siluro-Devonian time (fig. 5), continued through all post-Devonian intervals.

(3) Differential compaction around Silurian reefs, such as Raccoon Lake, produced the most striking features of pre-Chester Mississippian time (fig. 11, profile 2) and continued through later time.

(4) The Salem anticline is first clearly indicated in Chester time, as shown by profile 3 in figure 11.

(5) Monoclinal flexure of the DuQuoin axis began in post-Chester time and was essentially complete by Carbondale time (fig. 11, profile 4). The greatest movements of other tectonic axes in the area were contemporaneous with the folding of the DuQuoin monocline.

(6) The present structure—except for faulting—was developed by Carbondale time and has been only slightly modified since then.

(7) Faulting occurred in post-McLeansboro time (fig. 11, profile 6) and was probably entirely post-Pennsylvanian.

PROSPECTS FOR OIL DISCOVERIES

Drilling in the Centralia area has resulted in the discovery and development of sixteen oil fields (fig. 2), and a large number of dry holes have been drilled in the intervening areas. Although it seems probable that no large closed structures remain undiscovered in the area, there is a fair possibility that new productive areas will be discovered. A reef in secs. 34 and 35, T. 3 N., R. 1 W., has been suggested; if a reef exists here it may contain oil. Other reefs as yet unsuspected may exist in the area. More oil may be possible along the fault zone in a situation similar to that of the Junction City field. Because of the large number of known oil pay zones in the Centralia area—fifteen to date—and the possibility of undiscovered structures or stratigraphic traps, the prospects for further development in the area seem favorable.

BIBLIOGRAPHY

Bell, A. H., Structure of Centralia and Sandoval oil fields, Illinois: Illinois Geol. Survey Ill. Pet. 10, pp. 1–12, 1927.

__________, Role of fundamental geologic principles in the opening of the Illinois Basin: Economic Geology, vol. 36, no. 8, pp. 774–785, Dec. 1941; reprinted as Illinois Geol. Survey Circ. 75, 1941.

Butts, Charles, Geology and mineral resources of the Equality-Shawneetown area: Illinois Geol. Survey Bull. 47, pp. 14–51, 1925. Iowa, pp. 16–25; Chester, pp. 25–36; Pennsylvanian, pp. 39–51.

Caylor, Garth W., Devonian of the Centralia-Salem area: *in* Illinois Geol. Survey Bull. 68A, Symposium on Devonian stratigraphy, pp. 200–204, 1944.

Du Bois, E. P., Subsurface relations of the Maquoketa and Trenton formations in Illinois: Illinois Geol. Survey Rept. Inv. 105, 1945.

Folk, Stewart H., and Swann, David H., King oil field, Jefferson County, Illinois: Illinois Geol. Survey Rept. Inv. 119, 1946.

Grogan, Robert M., Structures due to volume shrinkage in the bedding-replacement fluorspar deposits of southern Illinois: Economic Geology, vol. 44, pp. 606–616, November 1949; reprinted as Illinois Geol. Survey Circ. 158, 1949.

Heinrich, Ross R., and Frank, Albert, The Illinois basin earthquake of November 17, 1937: Earthquake Notes, vol. 10, no. 3, pp. 1–7, 1937.

Landes, Kenneth K., Ehlers, G. M., and Stanley, George M., Geology of Mackinac Straits area: Michigan Geol. Survey Pub. 44, pp. 123–153, 1945.

Payne, J. N., Subsurface geology of the Iowa (Lower Mississippian) series in Illinois: Bull. Am. Assoc. Pet. Geol., vol. 24, pp. 225–236, 1940; reprinted as Illinois Geol. Survey Rept. Inv. 61, 1940.

Payne, J. Norman, and Willman, H. B., Geology and mineral resources of the Marseilles, Ottawa, and Streator quadrangles: Illinois Geol. Survey Bull. 66, 1942.

Siever, Raymond, The Mississippian-Pennsylvanian unconformity in southern Illinois, Bull. Am. Assoc. Pet. Geol., vol. 35, no. 3, pp. 542–581, March 1951; reprinted as Illinois Geol. Survey Rept. Inv. 152, 1951.

Swann, David H., and Atherton, Elwood, Subsurface correlations of Lower Chester strata of the Eastern Interior basin: Jour. Geol., vol. 56, no. 4, pp. 269–287, 1948; reprinted as Illinois Geol. Survey Rept. Inv. 135, 1948.

Thwaites, F. T., Buried pre-Cambrian of Wisconsin: Bull. Geol. Soc. Amer., vol. 42, pp. 719–750, 1931.

Weller, J. M., Geology and oil possibilities of extreme southern Illinois: Illinois Geol. Survey Rept. Inv. 71, pp. 16–42, 1940.

__________, Devonian system in southern Illinois: *in* Illinois Geol. Survey Bull. 68A, Symposium on Devonian stratigraphy, pp. 89–102, 1944.

Willman, H. B., Structure of the zinc-lead deposits of northwestern Illinois (abstract): Bull. Geol. Soc. Amer., vol. 56, p. 1212, 1945.

Workman, L. E., Subsurface geology of the Devonian in Illinois: *in* Illinois Geol. Survey Bull. 68A, Symposium on Devonian stratigraphy, pp. 189–199, 1944.

__________, Subsurface geology of the Chester series in Illinois: Bull. Am. Assoc. Pet. Geol., vol. 24, pp. 209–224, 1940; reprinted as Illinois Geol. Survey Rept. Inv. 61, 1940.

Workman, L. E., and Bell, A. H., Deep drilling and deeper oil possibilities in Illinois: Bull. Am. Assoc. Petr. Geol., vol. 32, pp. 2041–2062, 1948; reprinted as Illinois Geol. Survey Rept. Inv. 139, 1949.

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1954